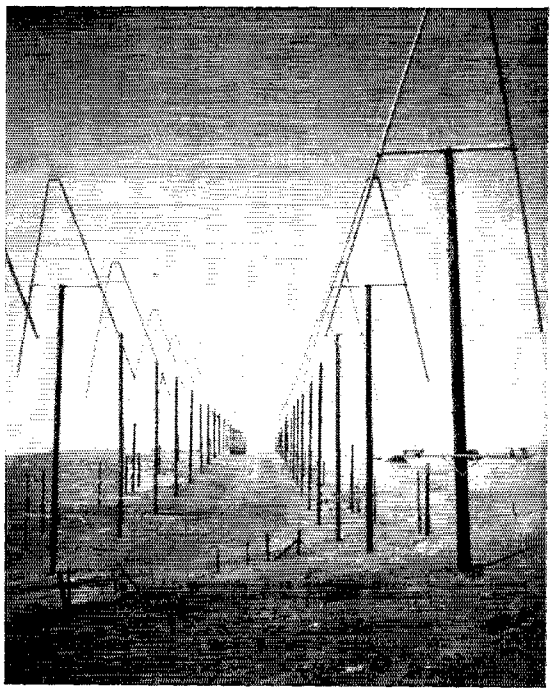


This field full of phased log-periodic antennas was used by the author to obtain reflections from the moon in the 10-meter band. In case you'd like to duplicate the feat, the array is 1200 feet long and 75 feet wide. It has a gain of 27 db.!

The Moonbounce Problem, 28 Mc. and Up

Basic Facts for Determining Equipment and Antennas Needed for Lunar Communication

BY H. T. HOWARD,* W6UGL

THE purpose of this article is to stimulate amateur interest in moonbounce communication, by presenting the basic parts of the problem, such as noise figure, path loss, and antenna gain, in familiar terms. Once these basic factors are understood, they can then be applied to equipment and antenna design for communication via the moon or man-made satellites.

Moonbounce was accomplished on ten meters several months ago at this station with about 1 kw. p.e.p. single sideband, using the array of 48 log periodics shown in the first photograph. The array is 1200 feet long by 75 feet wide, and it has a gain of 27 db., over the range of 20 to 65 Mc.! The beam produced is approximately 1½ degree thick by 30 degrees in azimuth and can be placed to intercept the moon or sun track for about two hours each day. Power is distributed in the array with open-wire line, and tapered sections to maintain the wide bandwidth, and in the usual operation *each antenna* handles from 5 to 10 kilowatts.

* Radioscience Laboratory, Stanford University, Stanford, Calif.

A circuit diagram of the array would look like a corporation organization chart; that is, it starts with one feed line and progressively branches down to the individual antennas which are specially designed and built log periodics, each having a pair of 40-foot booms and a total of 48 elements.

At each power division point there is a movable tap arranged so that the relative phase between antennas is completely adjustable. In practice, the phasing is changed each day to follow the moon's elevation. It takes two men with wrenches and a jeep about two hours to move all of the taps. The array is normally used with a 300-kw. (600-kw. p.e.p.) c.w. transmitter for radar studies of the solar corona and the ionized regions between the earth and the moon.[1]

The selection of ten meters for the moonbounce experiment mentioned above avoids controversy

[1] Research supported by the Electronics Research Directorate of the Air Force Cambridge Research Laboratories, Bedford, Mass., under contracts with Stanford University, Stanford, Calif.

over the use of large nonprivate antennas for v.h.f. records. Six or possibly fifteen meters might yield similar results if tried. The whole idea, though, is to demonstrate that the absolute minimum antennas for h.f. and lower v.h.f. moonbounce are ridiculously large for individual construction.

Since the array is linearly polarized, Faraday fading is a very important consideration,[2] and the unrecommended expedient of whistling into the microphone was used, until the signal faded up to a usable strength. Then the call was signed in voice and, with the help of some imagination, was received 2½ seconds later. The use of circular polarization will reduce fading, and is certainly required for any serious v.h.f. lunar-communication attempt.

The trick of ten-meter moonbounce points out several facts that will become obvious as you read further. First, station equipment needed for moonbounce on our lower bands is a minimum, and commercially available, but the antenna required is gigantic. Second, cosmic noise and ionospheric effects play a large role below about 100 Mc. With increasing frequency, the antenna becomes physically smaller, but the receiver and transmitter must be the best that amateur ingenuity can produce.

The average loss in decibels for the earth moon–earth path, assuming 500 watts of r.f. power at the antenna terminals and a moon reflectivity of about 7 per cent, is given in Fig. 1. Path loss will vary approximately ± 1 db. during each month as range to the moon changes.[3] Moon reflectivity is currently the subject of several scientific investigations, and while reflectivity appears to be higher at frequencies below 450 Mc., and is perhaps lower above that frequency, the figure given should be accurate enough for a first approach to the problem. If the transmitter power at the antenna terminals is less than 500 watts due to feed-line losses or other practical considerations (such as money) this path-loss number should be increased by the number of db. difference.

The next problem is that of receiver noise figure and sensitivity. Fig. 2 is a plot of cosmic noise *vs.* frequency, presented to give the equipment designer an idea of what is needed for a front end. The *min* and *max* lines show the sky temperatures and minimum usable noise figure that can be expected when the antenna is directed toward the coldest and hottest portions of the sky, respectively. This variation is easily observable even with simple equipment and is a good method of checking antenna and system performance.[4] Fortunately for the communications problem, larger areas of the sky are cold than are hot.

Below about 1000 Mc., cosmic noise is the

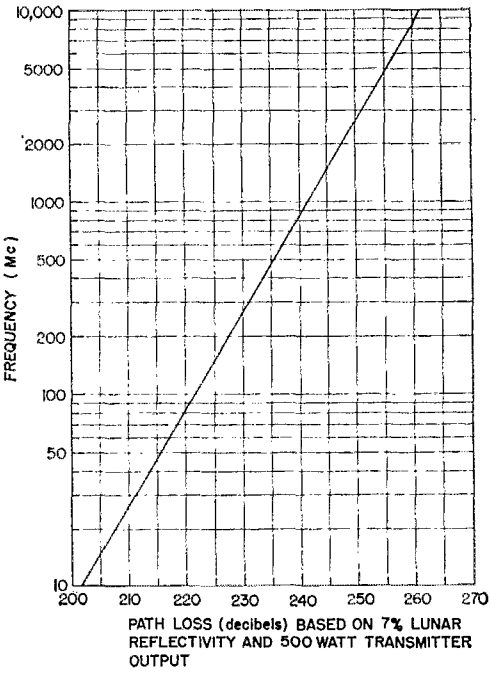


Fig. 1—Moonbounce-path loss *vs.* frequency.

dominant factor and varies with the portion of the galaxy observed. It can be seen that being cosmic-noise-limited, that is, having the feed-line loss and receiver-noise contribution less than the cosmic noise, at all times, is an engineering feat nearly impossible at 220 Mc. and higher, with the present state of the art.

Before going further, it is necessary to clear up some confusion concerning receiver sensitivity and noise figure that has arisen because of improper use of the relation:

Ideal receiver sensitivity = kTB

where

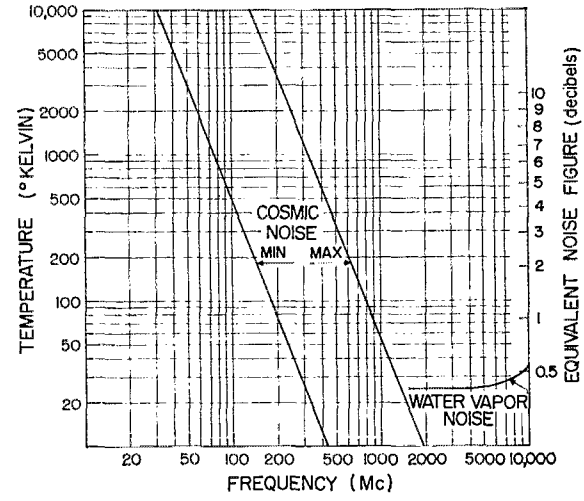


Fig. 2—Cosmic and water-vapor noise limits *vs.* frequency.

[2] Dyce, "The Appearance of the Moon at Radio Frequencies," *QST*, May, 1961.

[3] Pettengill, "Lunar Studies." Lecture notes presented at course on Radar Astronomy, summer session 1961, Massachusetts Institute of Technology, Cambridge, Mass.

[4] Downes, "A Simple Radio Telescope," *Sky and Telescope*, August, 1962.

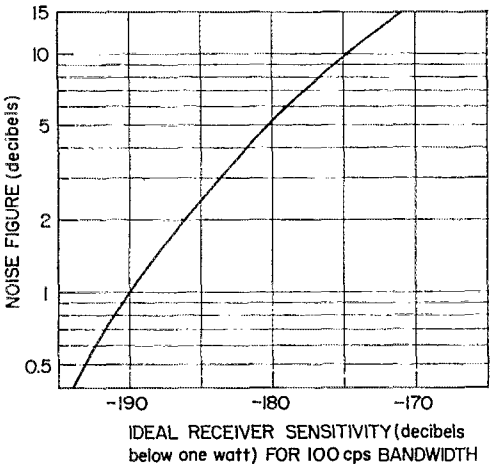


Fig. 3—Ideal receiver sensitivity *vs.* noise figure.

k is Boltzmann's constant, 1.38×10^{-23} joule/°K

T is temperature in degrees K

B is bandwidth in c.p.s.

If one uses room temperature of 290 degrees K, then it can be shown that:

Ideal receiver sensitivity (−dbw.) =

204 db. −10 log B −db. noise figure.

This relation is correct for systems with noise figures greater than 3 db. (system temperature greater than 290 degrees K), but needs revision to be correct for present-day low-noise amplifiers. By using an equivalent system temperature for T instead of 290 degrees K, we can still satisfy the IRE definition for noise figure and be consistent with present practice. All of this is simply saying that it is possible for a directive antenna and receiver at u.h.f. to look at a portion of the sky that is colder than 290 degrees K.

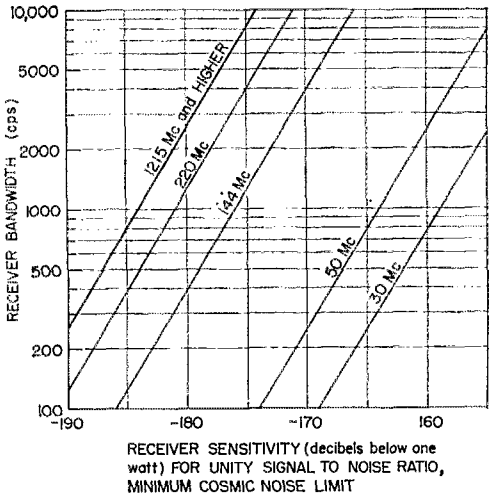


Fig. 4—Receiver sensitivity *vs.* bandwidth for the various amateur bands.

A plot of the above interpretation for a receiver with a 100-cycle bandwidth is shown in Fig. 3. There are some surprises in this graph that arise from proper use of noise figure. For instance, an improvement in receiver noise figure from 3 db. to 2 db. improves receiver sensitivity not just 1 db., but nearly 3. Going from a 10-db. crystal mixer to a 2-db. paramp yields a sensitivity improvement of 12 db. This makes it pretty obvious that the best possible noise figure and the lowest possible line losses are all important, at frequencies where system noise is greater than cosmic noise.

Fig. 4 uses the information of Fig. 2, and assumes that the system performs to the lower cosmic-noise limit. It shows what receiver sensitivity to expect in each case, for unity signal-to-noise ratio with various bandwidths. If the system is not cosmic noise-limited, the number obtained from Fig. 4 should be decreased by the number of db. difference between the ideal case of Fig. 4 and the actual system. Again, both noise figure and transmission-line loss enter here. The number from Fig. 4, as modified by reality, is the receiver sensitivity in decibels below 1 watt, and can be added algebraically to the path loss of Fig. 1 to obtain the two-way antenna gain necessary.

For example, select 1296 Mc. and assume a parametric-amplifier front end with a 2-db. noise figure [5] and 2 db. of feed-line losses. From Fig. 1 the total path loss is 244 db. and from Fig. 2 the system is definitely not cosmic noise-limited.

Example:

Fig. 1: Total path loss for 500 watts power output	244
Feed-line loss	2
	246 db.
Fig. 4: Cosmic-noise-limited receiver sensitivity (500 c.p.s. bandwidth)	−187 dbw.
Fig. 2: Receiver n.f. = 2 db.	= 170° K
Line loss = 2 db.	= 170° K
	340° K = 3.4 db.
Cosmic noise	= 0.5 db.
Fig. 3: Difference between 0.5 db. cosmic noise and 3.4 db. actual receiver system	+ 10 db.
	− 177 dbw.
	69 db.

$$\frac{69}{2} = 34.5 \text{ db.}$$

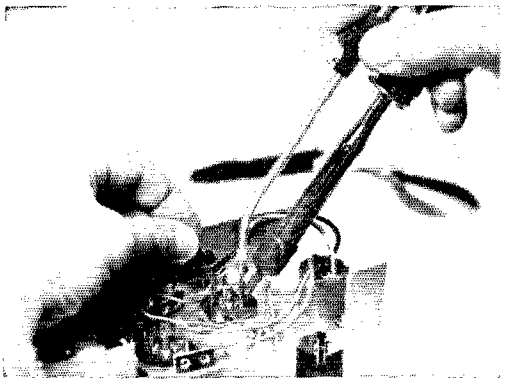
This is the antenna gain required at each station for unity signal-to-noise ratio in a 500-c.p.s. bandwidth, but as W1FZJ has pointed out,[6] the ear can be a narrower filter if properly trained.

(Continued on page 154)

[5] Troetschel and Heuer, "A Parametric Amplifier for 1296 Mc.," *QST*, January, 1961.

[6] Harris, "The World Above 50 Mc.," *QST*, June, 1961.

"The Third Hand"



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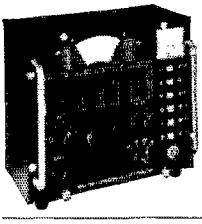

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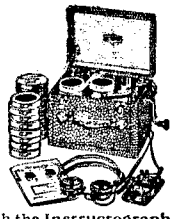

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The Moonbounce Problem

(Continued from page 22)

These figures show, among other things, that the initial 1296-Mc. moonbounce, with an 18-foot dish (35 db.) and 300 watts of transmitter power, was both a technical triumph and an operating feat. It is also clear that the higher frequencies are the logical choice for both commercial and amateur work of this type.

As Soifer[7] recently noted, the basic problem is to obtain adequate signal-to-noise ratio, and the graphs presented here should help the equipment- and antenna-oriented amateur get a feel for the moonbounce problem. It should be remembered, however, that marginal systems give marginal results (if any at all), and that these numbers should be used conservatively if reliable communication is the goal. QST

[7] Soifer, "Space Communication and the Amateur" *QST*, November, 1961.

Intermodulation Distortion

(Continued from page 57)

amplifier service show a decided improvement in IM distortion figures. Fig. 11 shows typical IM values for the 4CX3000A. Depending upon the value of resting plate current, the 4CX3000A is capable of delivering a p.e.p. output of 5.5 kilowatts with 3rd intermodulation products as low as −36 db. or more below the signal level. With the addition of ten or fifteen decibels of feedback, the construction of a high-power, high-quality linear amplifier having IM products in the region of −50 db. below the signal level becomes a reality.

Conclusion

The idealized vacuum tube is a 3/2-power-law device, and theoretically is incapable of low intermodulation distortion, except for low-efficiency class-A operation. By careful design of tube parameters aimed to remove the tube from this style

(Continued on page 156)

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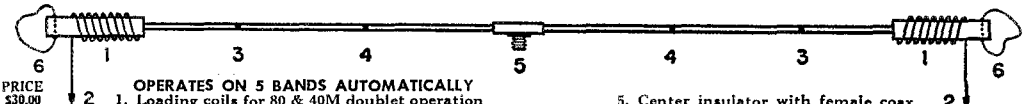

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